AD-A096 574   PENNSYLVANIA STATE UNIV UNIVERSITY PARK APPLIED RESE--ETC F/G 8/11
ANALYSIS OF SEISMIC REFRACTION DATA FROM NOVEMBER - DECEMBER 19--ETC(U
JAN 75 H S PIPER   N00017-73-C-1418

UNCLASSIFIED ARL/PSU/TM-75-12   NL

1 OF 1

END

DATE FILMED

4-81

DTIC

LEVEL II

AD A096574

DTIC
ELECTE
MAR 20 1981
S
E

The Pennsylvania State University
Intercollege Research Programs and Facilities
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, Pa. 16801

NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND

DDC FILE COPY

81 3 17 00

LEVEL II

ANALYSIS OF SEISMIC REFRACTION DATA FROM NOVEMBER-DECEMBER 1973 FIELD TRIP-CONSTANT DEPTH LEG.

Piper, [redacted], Jr

Technical Memorandum
File No. TM 75-12
January 13, 1975
Contract No. N00017-73-C-1418

Copy No. 19

The Pennsylvania State University
Institute for Science and Engineering
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, PA 16801

NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND

-1-

Subject: Analysis of Seismic Refraction Data from November-December 1973 Field Trip-Constant Depth Leg

References: [1] Hersey, J.B., E.T. Bunce, R.F. Wyrick and F.T. Dietz, "Geophysical Investigation of the Continental Margin Between Cape Henry, Virginia and Jacksonville, Florida," Bulletin of the Geological Society of America, Vol. 70, pp. 437-466, Apr. 1959.

Abstract:

A seismic refraction experiment was conducted, as part of the November-December, 1973 field tests off Daytona Beach, Florida. In the seismic experiment reported here, two pound charges were detonated one meter off the bottom and received on a vertical hydrophone array. The experiment was conducted along two legs; a constant depth leg and a leg along a sloping bottom. Along each leg, charges were detonated at ranges from about 1 km to 10 km. The recorded signals along the constant depth leg have been examined and four distinct refracted arrivals have been identified. The travel time versus distance curves for these different arrivals have been analyzed and layer thicknesses and propagation velocities for the different sedimentary layers have been obtained. The data presented here gives a description of the bottom properties that are important in modeling the sound propagation characteristics for this area.

Introduction

During the field trip conducted in November and December, 1973 in conjunction with NRL, a seismic refraction experiment was conducted. In this experiment, two pound charges were deployed from the ship moving at six knots, and detonated one meter from the bottom. The signals were received on a vertical hydrophone array and transmitted to the ship where the signals were recorded on magnetic tape. The amplifier gains were adjusted so that the refracted signal arrivals in the bottom (ground waves) could be detected. The shots were made along two legs; a constant water depth leg, and a leg along a sloping bottom, with the propagation from shallower to deeper water. On each leg, the shots were made from ranges of about 1 km to 10 km. In this report, the results of the constant depth leg experiment will be examined.

A hydrophone (instant shot hydrophone) was trailed about 200 feet behind the ship and the signal received from the explosion on this hydrophone provided a time base for determining the travel time for the various signal arrivals on the vertical receiving array. The results to be presented here were received on the bottom hydrophone, which was about three meters from the bottom.

Analysis

Since the instant shot hydrophone was not located at the point where the charge was detonated, we must make a correction to the travel time determined by the time difference between the instant shot time and the time of arrival of the various signals. The geometry is shown in Figure 1.

The ship was moving at six knots and the charges had a 65 second fuse. Thus d, the distance from the stern of the ship to the point where the shot is detonated, is given by

$$d = (6 \text{ knots})\ (65 \text{ sec.}) = 658.7 \text{ feet.} \tag{1}$$

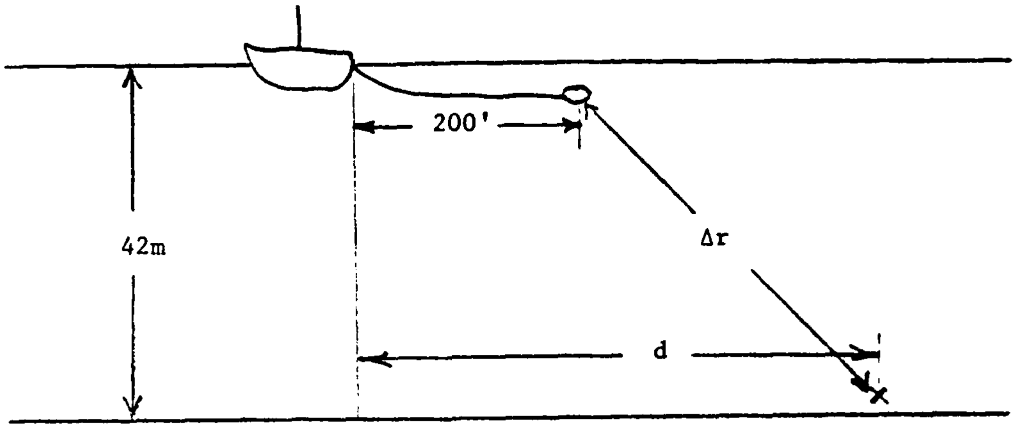


FIGURE 1

The water depth was about 42 meters and the charges were detonated one meter from the bottom. The instant shot hydrophone was streaming 200 feet behind the ship, and near the surface. We will assume that the instant shot hydrophone was 120 feet above the charge depth. Thus,

$$\begin{aligned} \Delta r &= [(658.7 - 200)^2 + (120)^2]^{1/2} \\ &= 474 \text{ feet} \qquad\qquad (2) \\ &= 144.5 \text{ meters.} \end{aligned}$$

Hence, since the measured sound velocity in the water was 1533 m/sec., the time correction is given by

$$\Delta\tau = \frac{144.5 \text{ m}}{1533 \text{ m/sec.}} = 0.094 \text{ sec.} \qquad (3)$$

In Figures 2 through 11, the received signals for the ten shots on the constant depth leg for the bottom hydrophone are shown. These reproductions do not always show the different signal arrivals as clearly as the raw data recordings nor is some of the supplementary data shown here. Notice also that the time scale is not the same on all figures. However, if we examine these figures, we see that as many as four signal arrivals, in addition to the water wave signal, can be seen. The travel times for each of these various signals are given in Table 1, where the correction given in (3) has been made. The ranges for the various shots were determined from the time of arrival of the water wave signal and the known sound velocity in the water. The numbers in parentheses in Table 1 will be explained later.

January 13, 1975
HSP:dcj
Serial No. R-1213

TABLE 1

Travel Time, τ, seconds

Range, R, m.	W	A	B	C	D
10,300	6.719	5.977 (5.979)	5.508 (5.485)	4.680 (4.669)	(3.238)
9,234	6.023	5.343 (5.360)	4.914 (4.919)	4.210 (4.200)	2.976 (2.959)
8,192	5.344	4.766 (4.756)	4.352 (4.366)	3.735 (3.741)	2.656 (2.686)
7,150	4.664	4.156 (4.151)	3.797 (3.813)	3.258 (3.282)	2.453 (2.413)
6,096	3.977	3.532 (3.539)	3.258 (3.254)	2.805 (2.818)	2.102 (2.137)
5,018	3.273	2.929 (2.913)	2.679 (2.681)	2.359 (2.343)	1.851 (1.855)
4,024	2.625	2.344 (2.337)	2.156 (2.154)	1.906 (1.906)	(1.595)
3,018	1.969	1.750 (1.753)	1.617 (1.6[illegible])	1.469 (1.463)	1.344 (1.332)
2,036	1.328	1.195 (1.183)	1.109 (1.099)	1.031 (1.030)	(1.075)
1,126	0.735	0.656 (0.655)	0.633 (0.616)	(0.630)	(0.836)

The travel times versus ranges have been plotted in Figure 12 and we see that the arrivals lie nearly on straight lines. If we find the best linear fit to minimize the mean square error, we obtain

$$\tau - \overline{\tau} = \frac{\sum_{1}^{n} \tau_i R_i - n\overline{\tau}\,\overline{R}}{\sum_{1}^{n} (R_i)^2 - n(\overline{R})^2} (R - \overline{R}) , \tag{4}$$

where the overbar denotes average value. Using (4), we find that the best linear fits are given by

$$\text{Line A:} \quad \tau = 0.0005804R + 0.00122 \tag{5}$$

$$\text{Line B:} \quad \tau = 0.0005308R + 0.01801 \tag{6}$$

$$\text{Line C:} \quad \tau = 0.0004403R + 0.1339 \tag{7}$$

$$\text{Line D:} \quad \tau = 0.0002617R + 0.5417 \tag{8}$$

Substituting the ranges given in Table 1 into these equations, we find the values of travel time shown in parentheses in Table 1. Notice that the agreement is excellent and that the points all lie very nearly on the computed lines. Note also that the arrival at 0.633 seconds at a range of 1,126 meters should probably have been assigned to line C rather than line B.

We now want to relate the observed travel time versus range data to the bottom parameters. We will assume a layered bottom with horizontal interfaces.

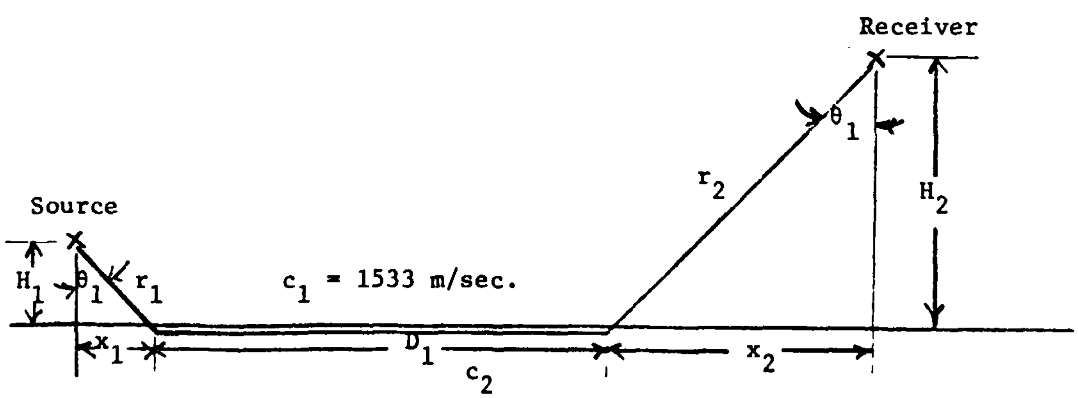


FIGURE 13

Figure 13 shows the geometry for arrival A. The sound hits the bottom at the critical angle, is refracted along the interface and travels with the velocity c_2. It leaves the interface at the critical angle and travels to the receiver. We have that

$$\sin\theta_1 = \frac{c_1}{c_2}$$

$$r_1 = \frac{H_1}{\cos\theta_1} = \frac{H_1}{\sqrt{1 - c_1^2/c_2^2}} = \frac{c_2 H_1}{\sqrt{c_2^2 - c_1^2}}$$

$$x_1 = r_1 \sin\theta_1 = \frac{c_1 H_1}{\sqrt{c_2^2 - c_1^2}}$$

$$r_2 = \frac{c_2 H_2}{\sqrt{c_2^2 - c_1^2}}$$

$$x_2 = \frac{c_1 H_2}{\sqrt{c_2^2 - c_1^2}}$$

$$D_1 = R - x_1 - x_2$$

Then, the travel time, τ, is given by

$$\tau = \frac{r_1}{c_1} + \frac{D_1}{c_2} + \frac{r_2}{c_1} = \frac{D_1}{c_2} + \frac{r_1 + r_2}{c_1}$$

$$= \frac{R}{c_2} + \frac{r_1 + r_2}{c_1} - \frac{x_1 + x_2}{c_2}$$

$$\tau = \frac{R}{c_2} + \frac{c_2(H_1 + H_2)}{c_1\sqrt{c_2^2 - c_1^2}} - \frac{c_1(H_1 + H_2)}{c_2\sqrt{c_2^2 - c_1^2}}$$

$$= \frac{R}{c_2} + (H_1 + H_2)\,\frac{\sqrt{c_2^2 - c_1^1}}{c_1 c_2}$$

Using (5), we have

$$c_2 = \frac{1}{0.0005804} = 1723 \text{ m/sec.} \tag{9}$$

and

$$(H_1 + H_2)\,\frac{\sqrt{c_2^2 - c_1^2}}{c_1 c_2} = 0.00122. \tag{10}$$

Using $c_1 = 1533$ m/sec. and $c_2 = 1723$ m/sec., we find

$$H_1 + H_2 = 4.1 \text{ meters.}$$

Since the source was 1 meter off the bottom and the receiver was about 3 meters off the bottom, we see that the agreement is excellent.

We now consider arrival B. In what follows, we will neglect H_1 and H_2 and assume that the source and receiver are both on the bottom, as shown in Figure 14.

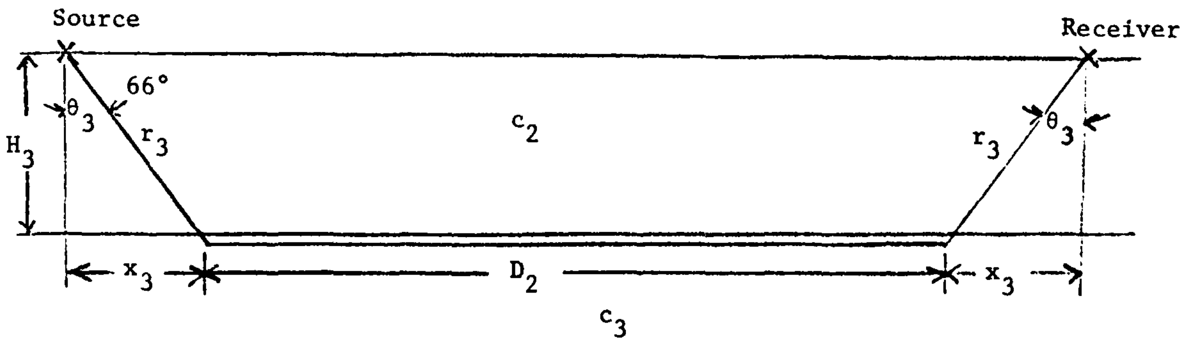


FIGURE 14

We have

$$\sin\theta_3 = \frac{c_2}{c_3}$$

$$r_3 = \frac{c_3 H_3}{\sqrt{c_3^2 - c_2^2}}$$

$$x_3 = \frac{c_2 H_3}{\sqrt{c_3^2 - c_2^2}}, \text{ and}$$

$$\tau = \frac{D_2}{c_3} + \frac{2r_3}{c_2}$$

$$= \frac{R}{c_3} + \frac{2H_3\sqrt{c_3^2 - c_2^2}}{c_2 c_3} .$$

From (6), we have

$$c_3 = \frac{1}{0.0005308} \quad \text{and} \quad \frac{2H_3\sqrt{c_3^2 - c_2^2}}{c_2 c_3} = 0.01801.$$

Thus,

$$c_3 = 1884 \text{ m/sec. and} \tag{11}$$

$$H_3 = 38.4 \text{ m.} \tag{12}$$

We will now examine arrival C as shown in Figure 15.

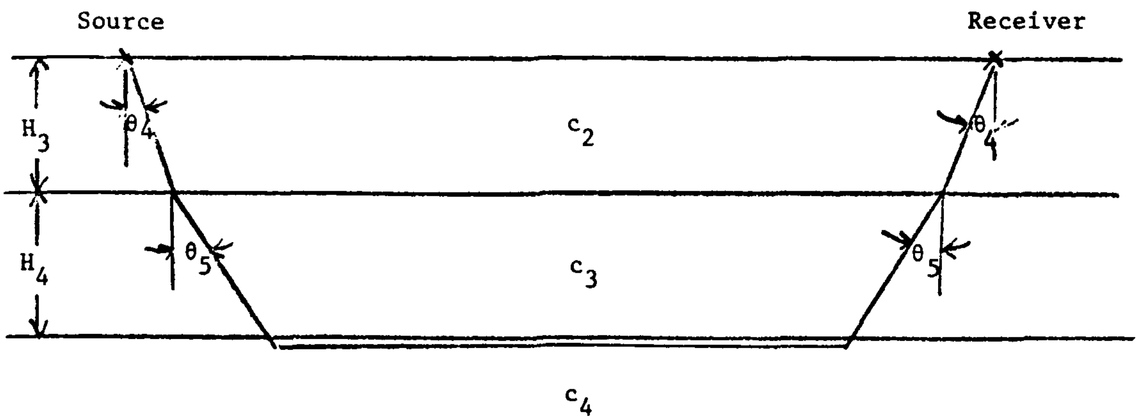


FIGURE 15

We have

$$\frac{\sin\theta_4}{c_2} = \frac{\sin\theta_5}{c_3}$$

$$\sin\theta_5 = \frac{c_3}{c_4} .$$

Using elementary geometry, as above, we find

$$\tau = \frac{R}{c_4} + \frac{2H_3\sqrt{c_4^2 - c_2^2}}{c_4 c_2} + \frac{2H_4\sqrt{c_4^2 - c_3^2}}{c_4 c_3} . \qquad (13)$$

But, from (7) we have

$$\tau = 0.0004403\ R + 0.1339.$$

Thus,

$$c_4 = \frac{1}{0.0004403} = 2271\ \text{m/sec.} \qquad (14)$$

and

$$\frac{2H_3\sqrt{c_4^2 - c_2^2}}{c_4 c_2} + \frac{2H_4\sqrt{c_4^2 - c_3^2}}{c_4 c_3} = 0.1339.$$

Using the values found for c_2, c_3, c_4 and H_3 in (9), (1), (14) and (12), we obtain,

$$H_4 = 176.9\ \text{m.} \qquad (15)$$

Finally, we will consider arrival D as shown in Figure 16.

We have that

$$\frac{\sin\theta_6}{c_2} = \frac{\sin\theta_7}{c_3} = \frac{\sin\theta_8}{c_4} , \quad \sin\theta_8 = \frac{c_4}{c_5} .$$

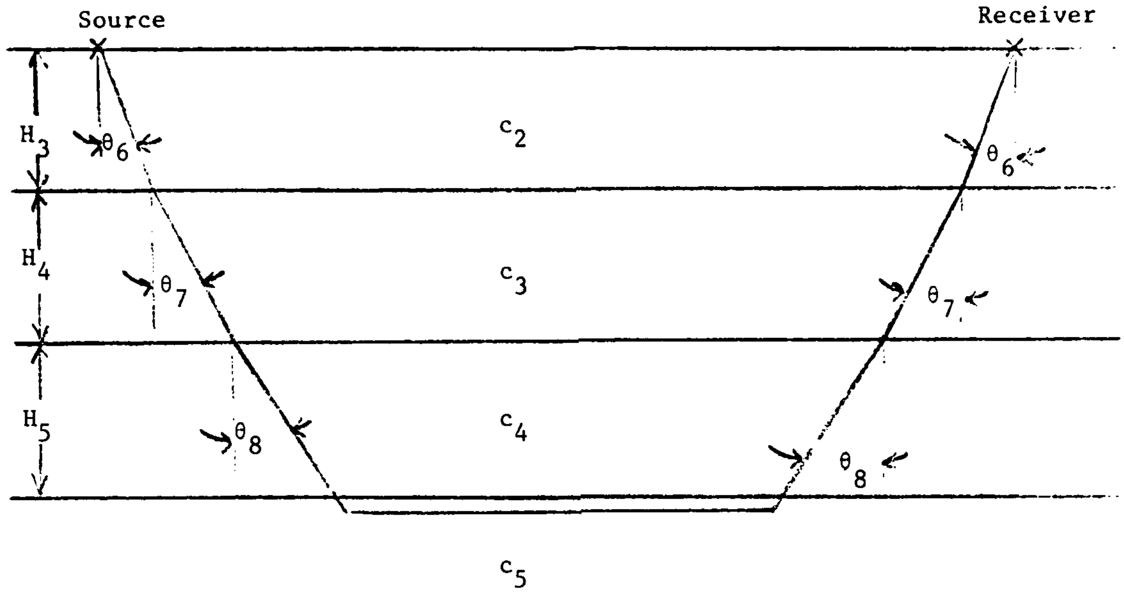


FIGURE 16

By the same procedure as before, we find for the travel time,

$$\tau = \frac{R}{c_5} + \frac{2H_3\sqrt{c_5^2 - c_2^2}}{c_2 c_5} + \frac{2H_4\sqrt{c_5^2 - c_3^2}}{c_3 c_5} + \frac{2H_5\sqrt{c_5^2 - c_4^2}}{c_4 c_5}.$$

But from (8), we have

$$\tau = 0.0002617\ R + 0.5417.$$

Thus,

$$c_5 = \frac{1}{0.0002617} = 3820 \text{ m/sec.} \tag{16}$$

and

$$\frac{2H_3\sqrt{c_5^2 - c_2^2}}{c_2 c_5} + \frac{2H_4\sqrt{c_5^2 - c_3^2}}{c_3 c_5} + \frac{2H_5\sqrt{c_5^2 - c_4^2}}{c_4 c_5} = 0.5417.$$

Using the values for c_2, c_3, c_4, H_3 and H_4 found above, we obtain

$$H_5 = 478.1 \text{ m.} \tag{17}$$

Discussion of Results

Based on the analysis given above, we postulate that the sedimentary structure in the area where the seismic refraction experiment was made is that shown in Figure 17. In reference [1], the results of a large number of seismic refraction profiles are given for the same general area as the profile analyzed here. In Table 2 of that report, layer velocities and layer thicknesses are given for profiles made in continental shelf locations. For the seismic profiles that were reported in that paper, much longer ranges and much larger charges were used than for the profile reported here. Consequently, information was obtained for much deeper layers than was obtained from our data. On the other hand, since the profile was obtained by using short range, closely spaced shots in the experiment reported here, the resulting data on the uppermost sedimentary layers should be more reliable than that reported in reference [1].

If we examine Table 2 of reference [1], we see that a low velocity layer, denoted by Layer A, was observed on nearly all the profiles. The velocity associated with this layer varied from 1660 m/sec. to 1900 m/sec., with layer thicknesses ranging from 50 m to 580 m. The velocity found for the uppermost layer in the test reported here, 1723 m/sec., is consistent with these results. However, the thickness we found, 38 m, is slightly less than any reported in reference [1]. The second layer shown in reference [1], Layer B, was observed on only a few profiles, and in only one case was both Layer A and Layer B present. The velocities reported for this layer ranged from 1920 m/sec. to 2050 m/sec., with thicknesses varying from 60 m to 630 m. Thus, the velocity observed here, 1884 m/sec., is slightly less than that found in reference [1]. The layer thickness observed for this layer is consistent with the earlier results. The next layer, C, reported in the earlier work was the most consistent layer since it was observed on every profile except one. The signal arrival associated with this layer was the most prominent feature observed in our received signals, i.e. the signal was very strong and very distinct. The velocities found for Layer C in reference [1] varied from 2250 m/sec. to 2880 m/sec., with thicknesses varying between 190 m and 2.45 km. Thus, the results we obtained, 2271 m/sec. and 478 m are consistent with the

reported results. The next layer reported in reference [1] had velocities between 3160 m/sec. and 3880 m/sec. The velocity obtained here for this layer was 3820, which again is consistent with the earlier results. In reference [1], results are also given for a number of deep, higher velocity layers, which were not observed in our experiment due to the short ranges that were used.

Recommendations

Since the sediments deeper than several water depths are not expected to have a significant effect on sound transmission, except for extremely low frequencies, it is recommended that the deeper layers be neglected in modeling the bottom for this location. Based on the results of this experiment, the bottom in this area should be modeled by a layer of velocity 1723 m/sec. with a thickness of 38 m on top of a half-space with velocity 1884 m/sec.

Acknowledgement

This work was performed at the Applied Research Laboratory, the Pennsylvania State University under contract with the Naval Sea Systems Command. The cooperation of the Naval Research Laboratory in allowing ARL to participate in this field experiment is greatly appreciated.

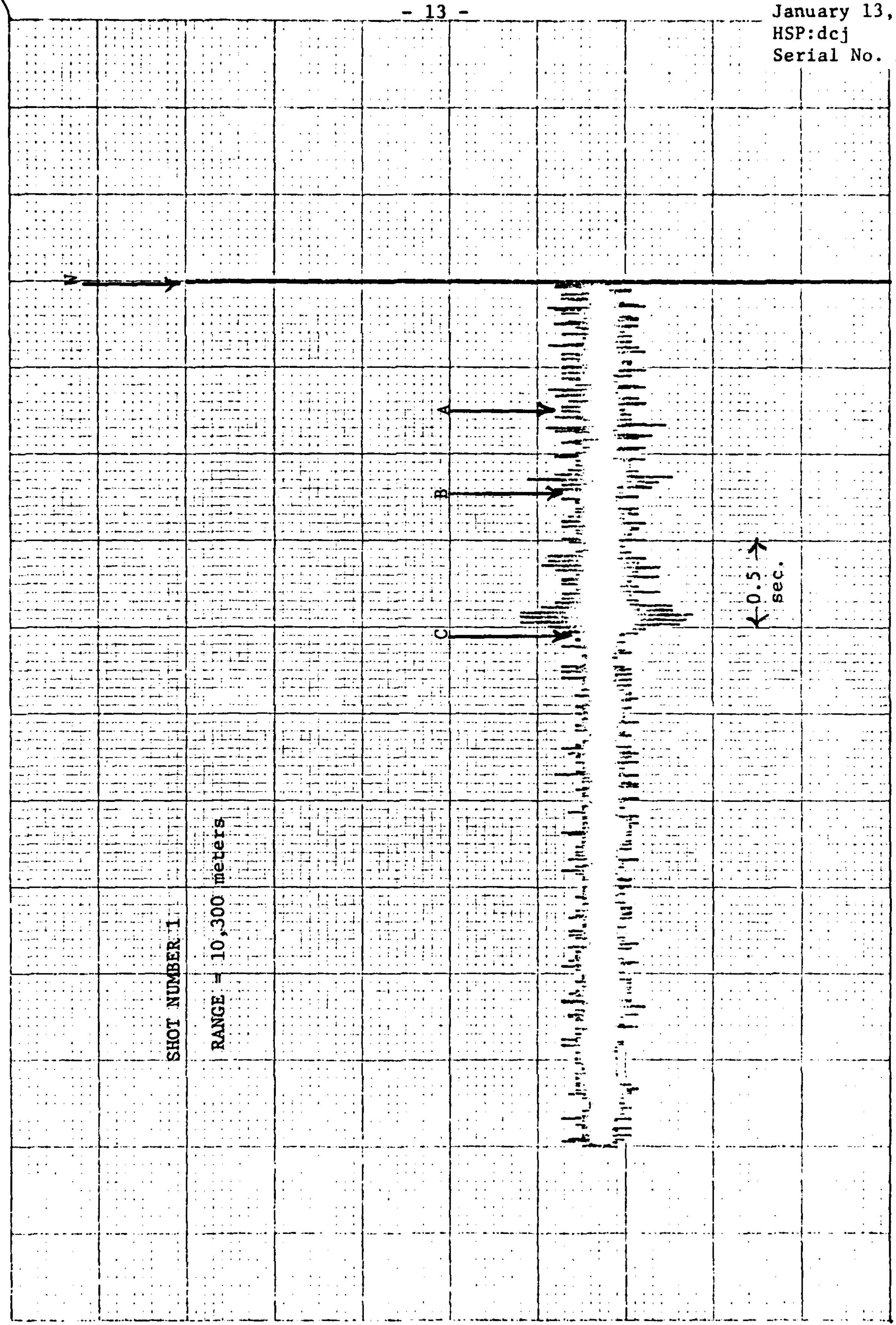


FIGURE 2

January 13, 1975
HSP:dcj
Serial No. R-1213

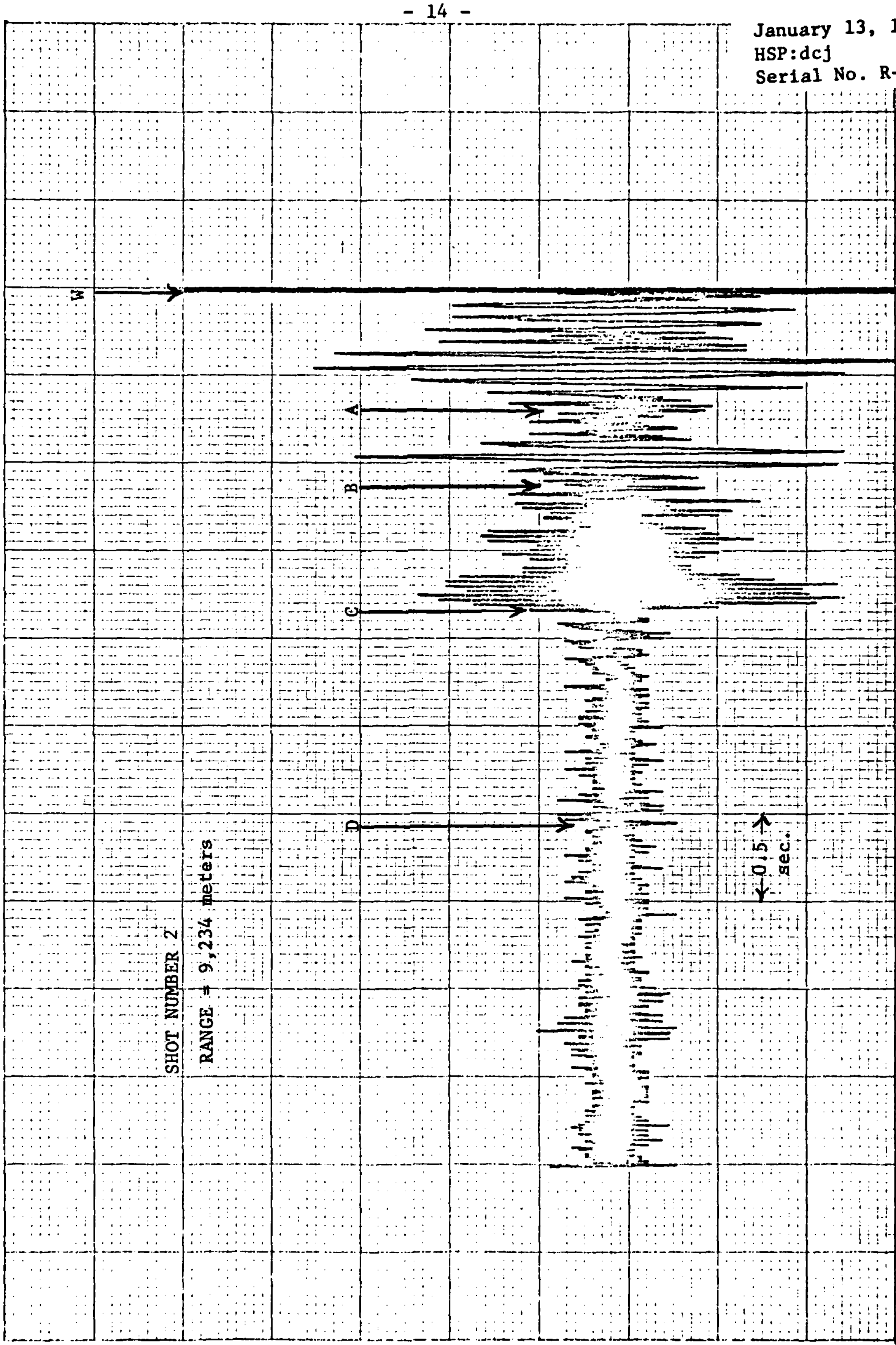


FIGURE 3

January 13, 1975
HSP:dcj
Serial No. R-121

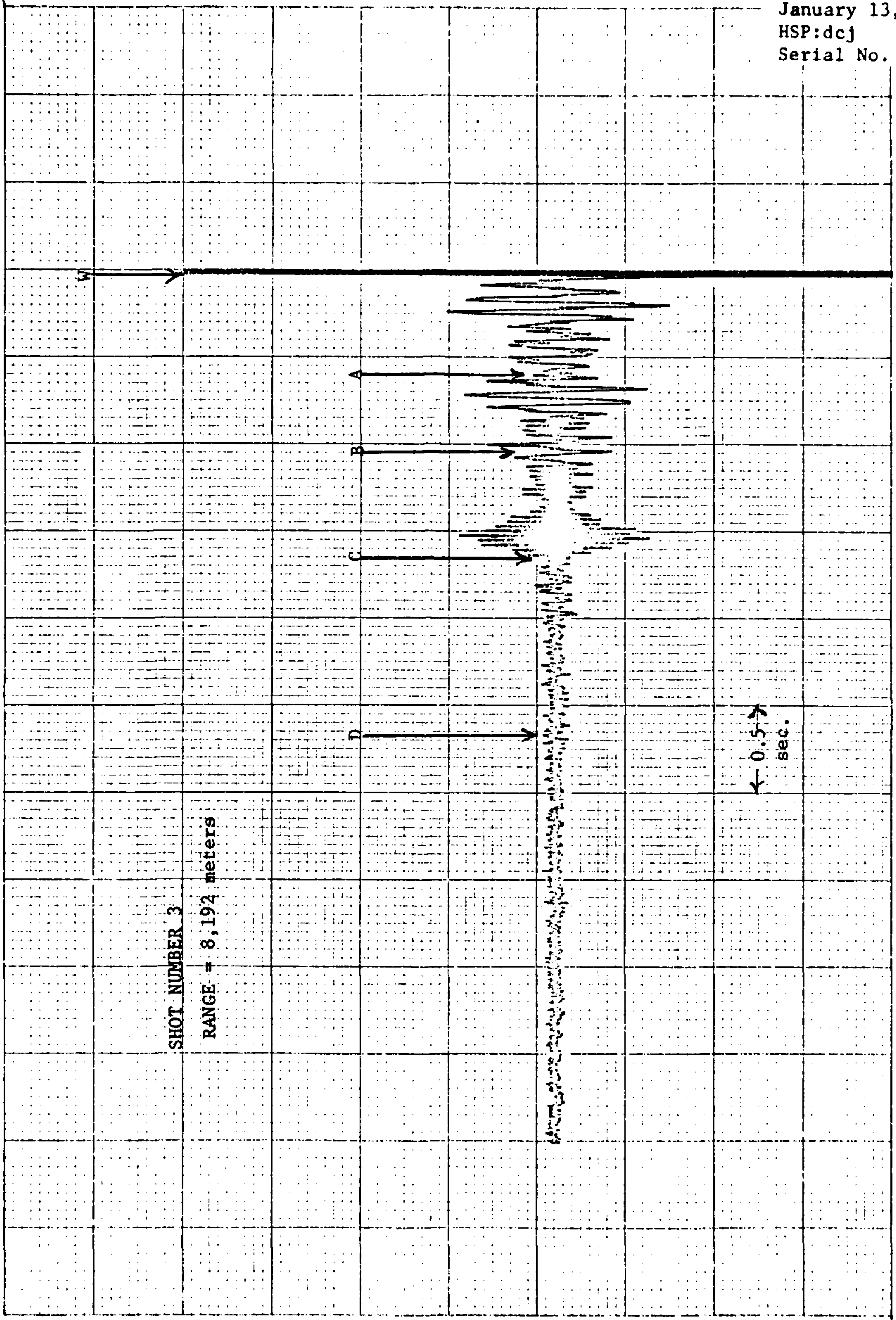


FIGURE 4

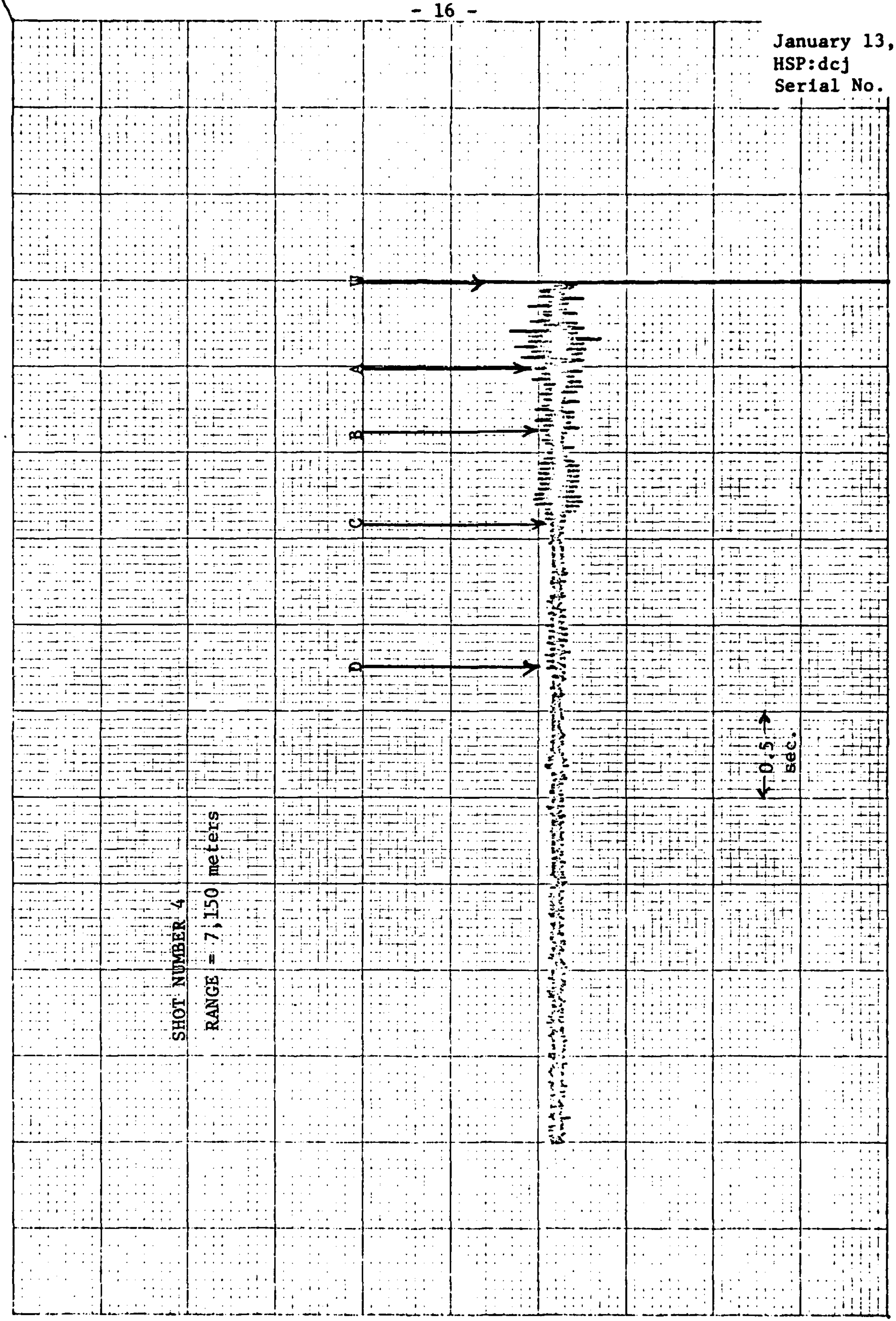


FIGURE 5

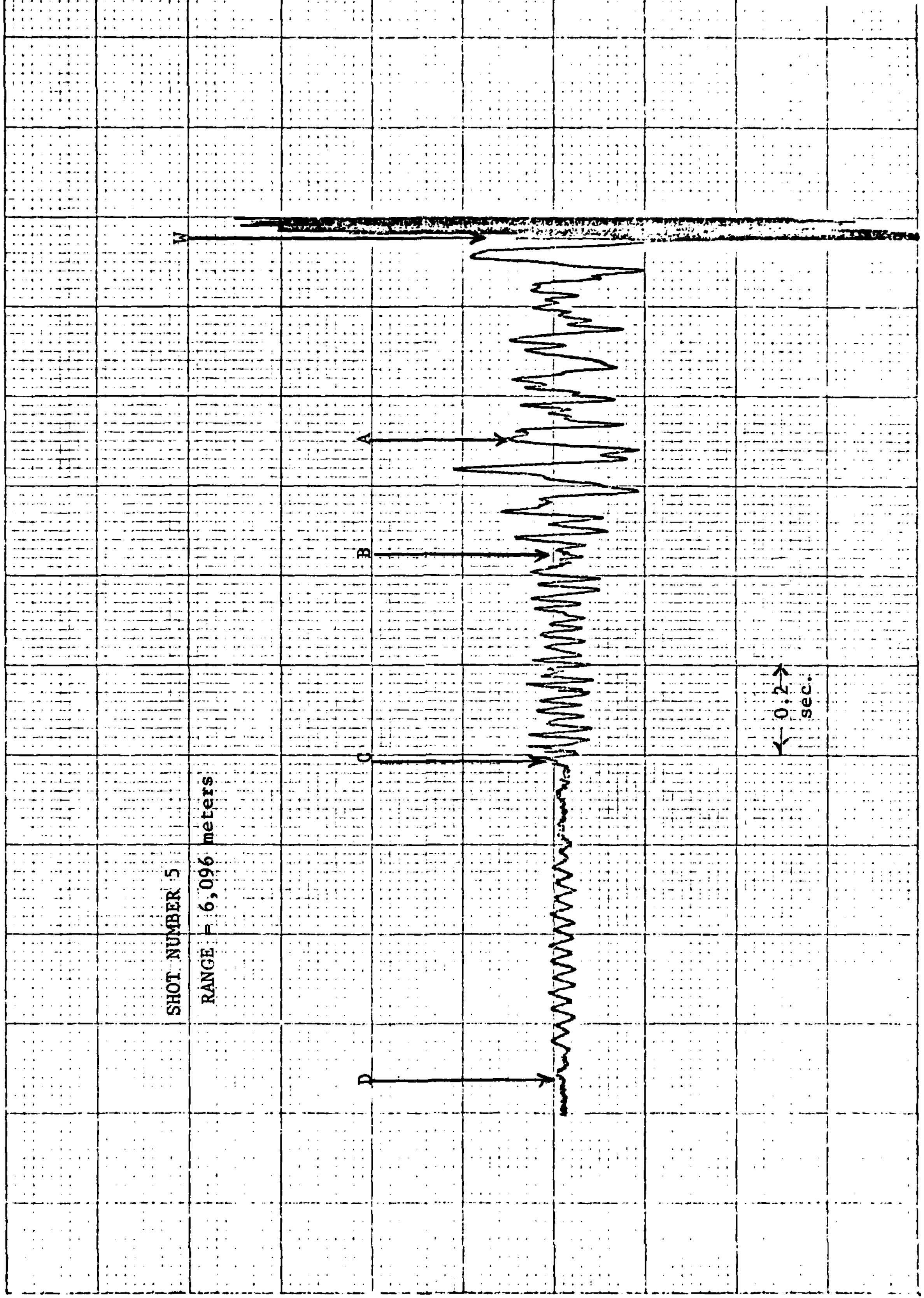


FIGURE 6

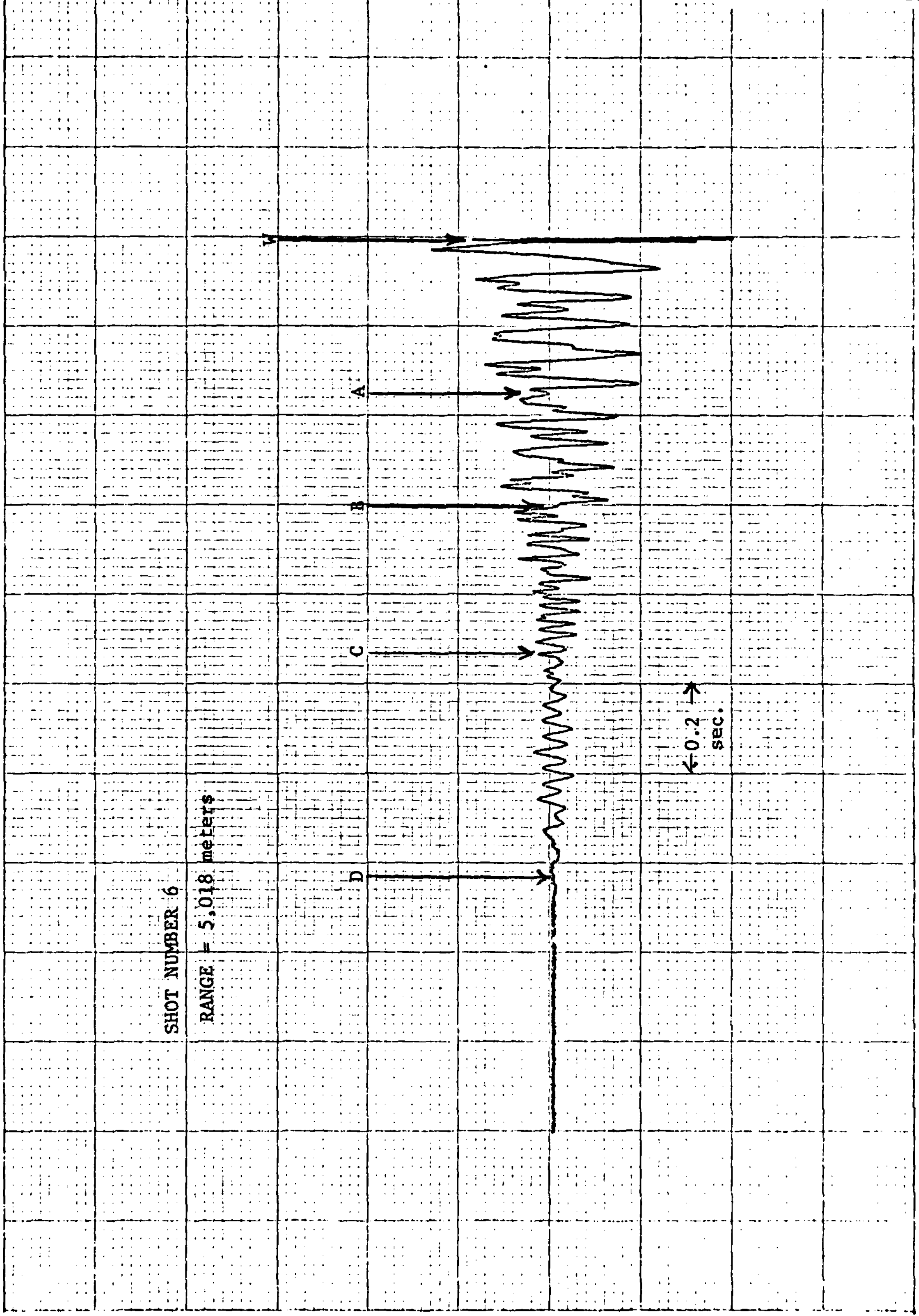


FIGURE 7

January 13, 1975
HSP:dcj
Serial No. R-1213

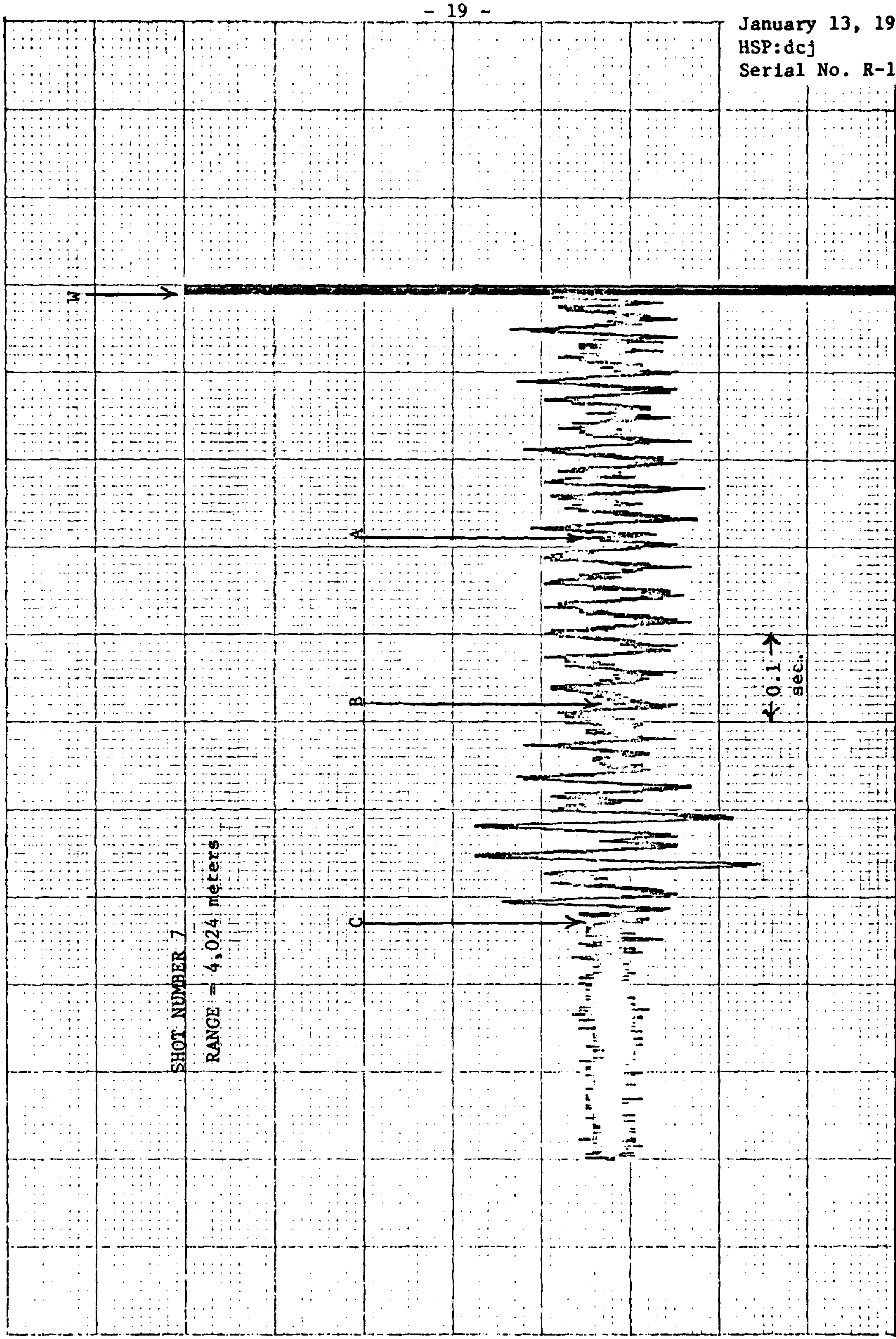


FIGURE 8

January 13, 1975
HSP:dcj
Serial No. R-1213

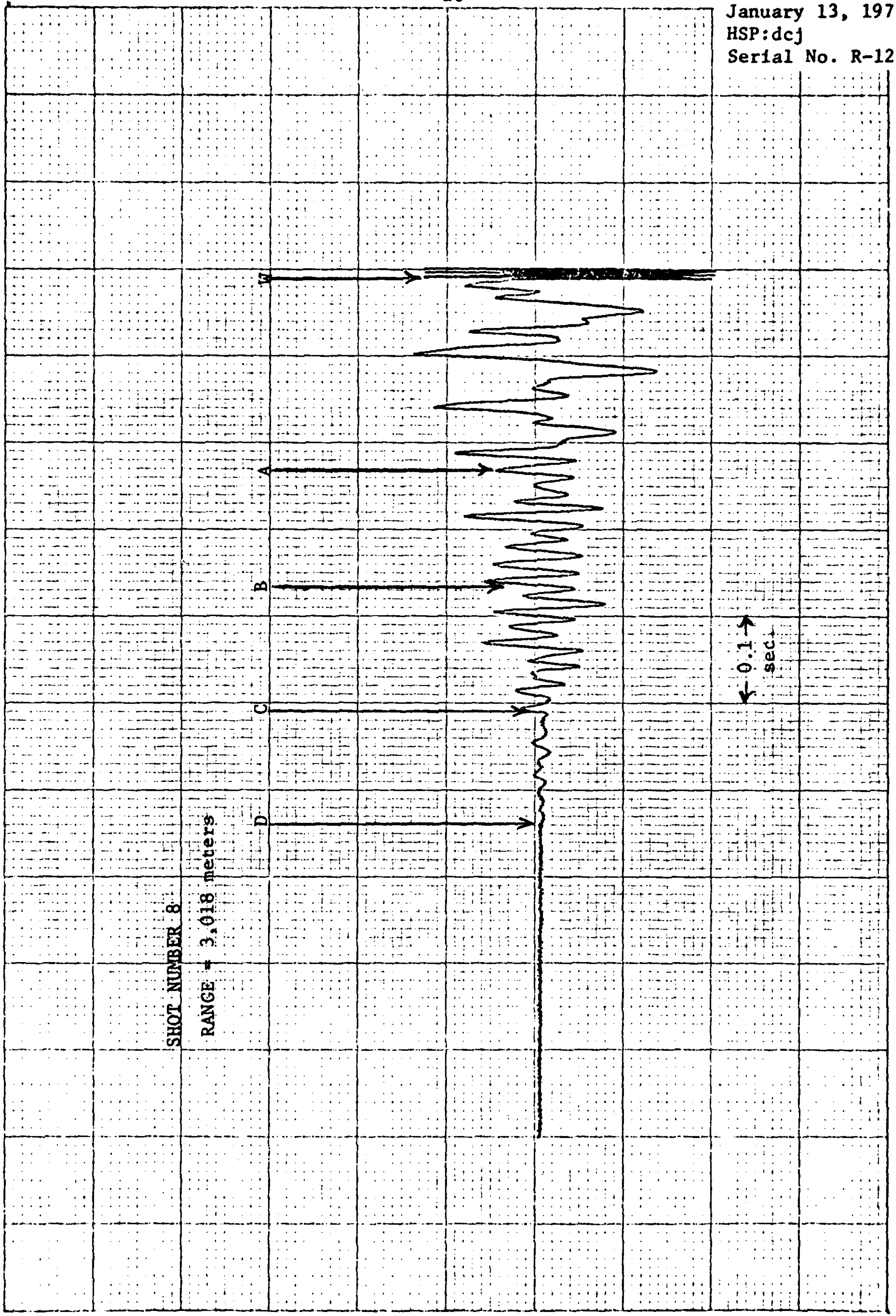


FIGURE 9

January 13, 1975
HSP:dcj
Serial No. R-1213

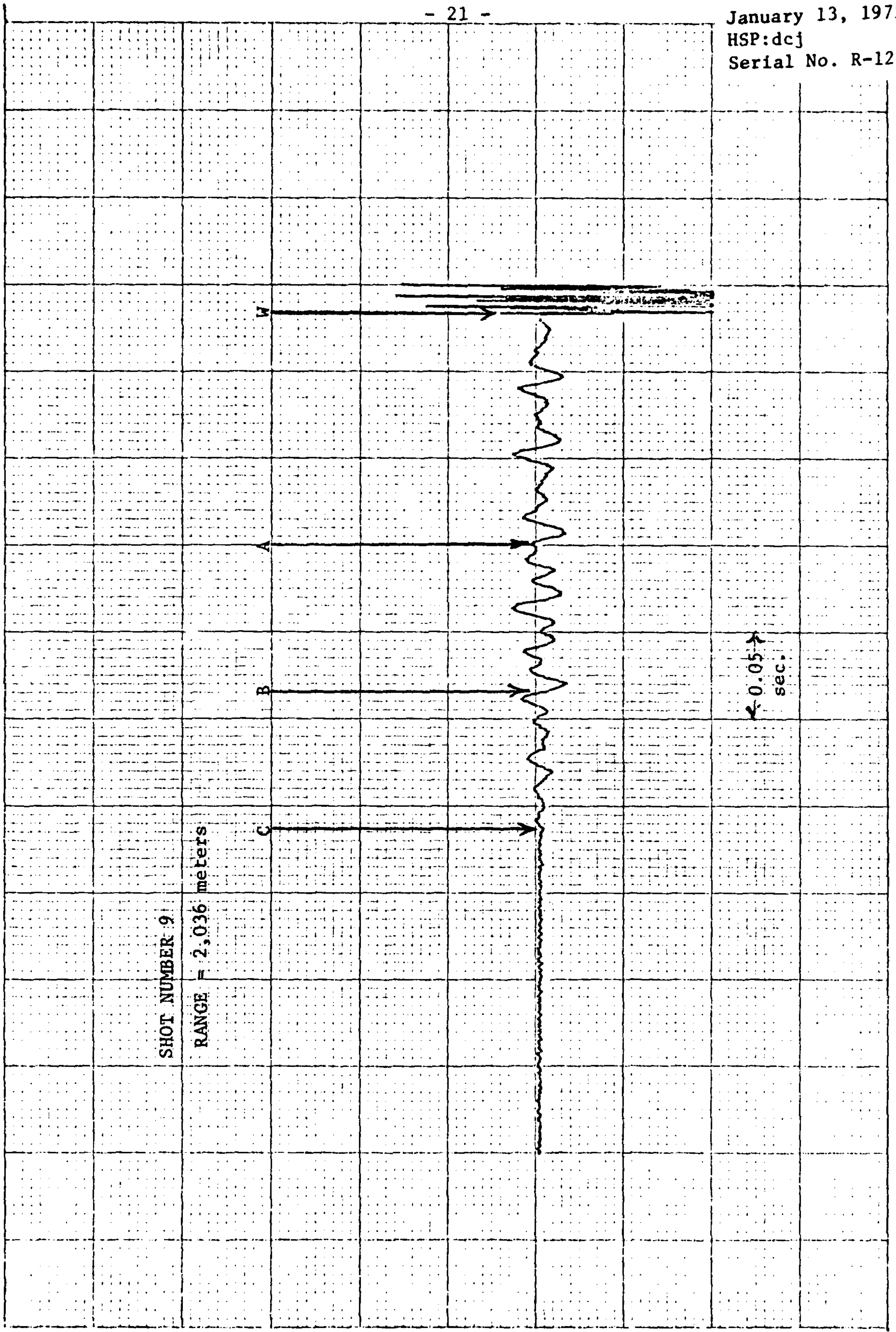


FIGURE 10

January 13, 1975
HSP:dcj
Serial No. R-1215

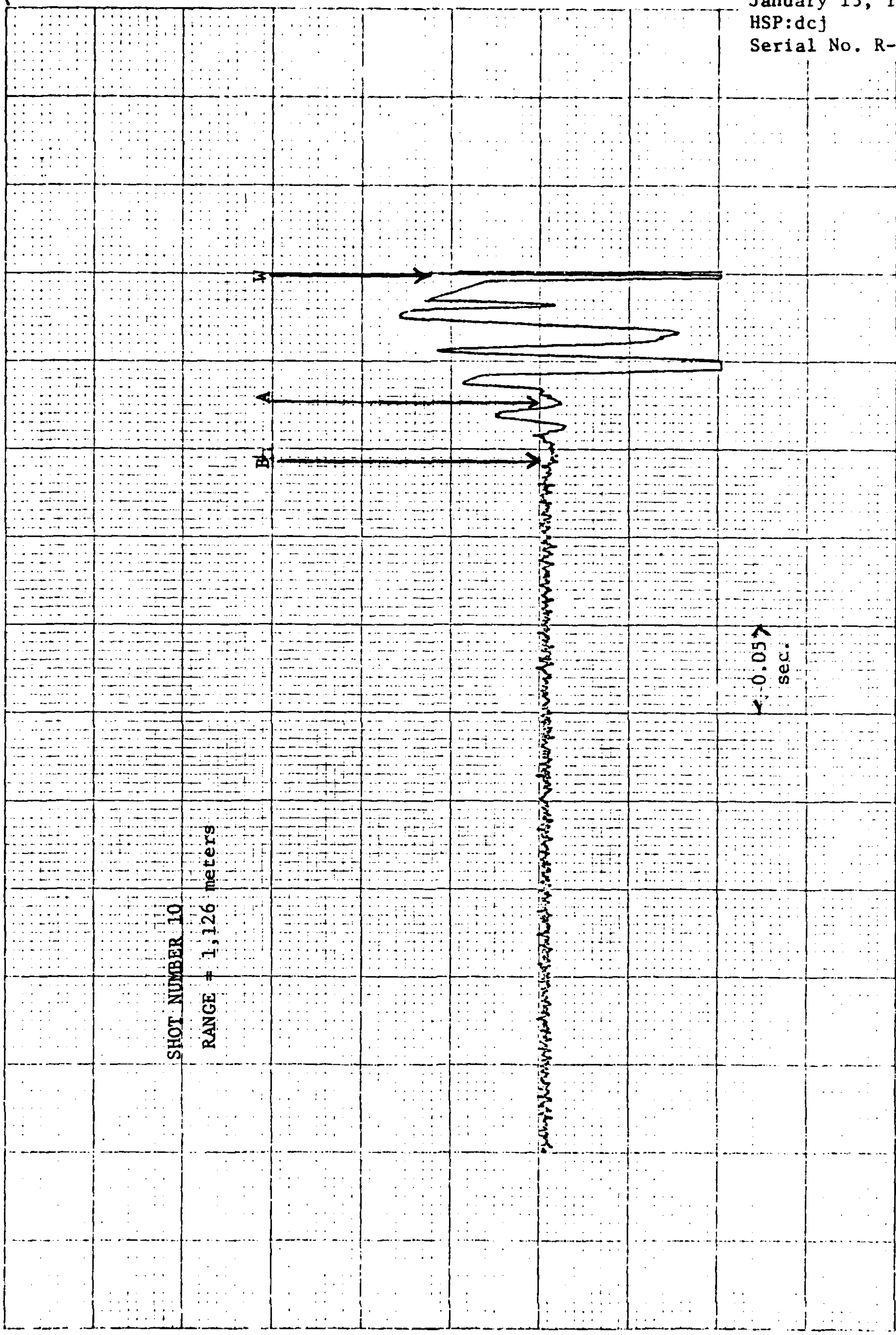
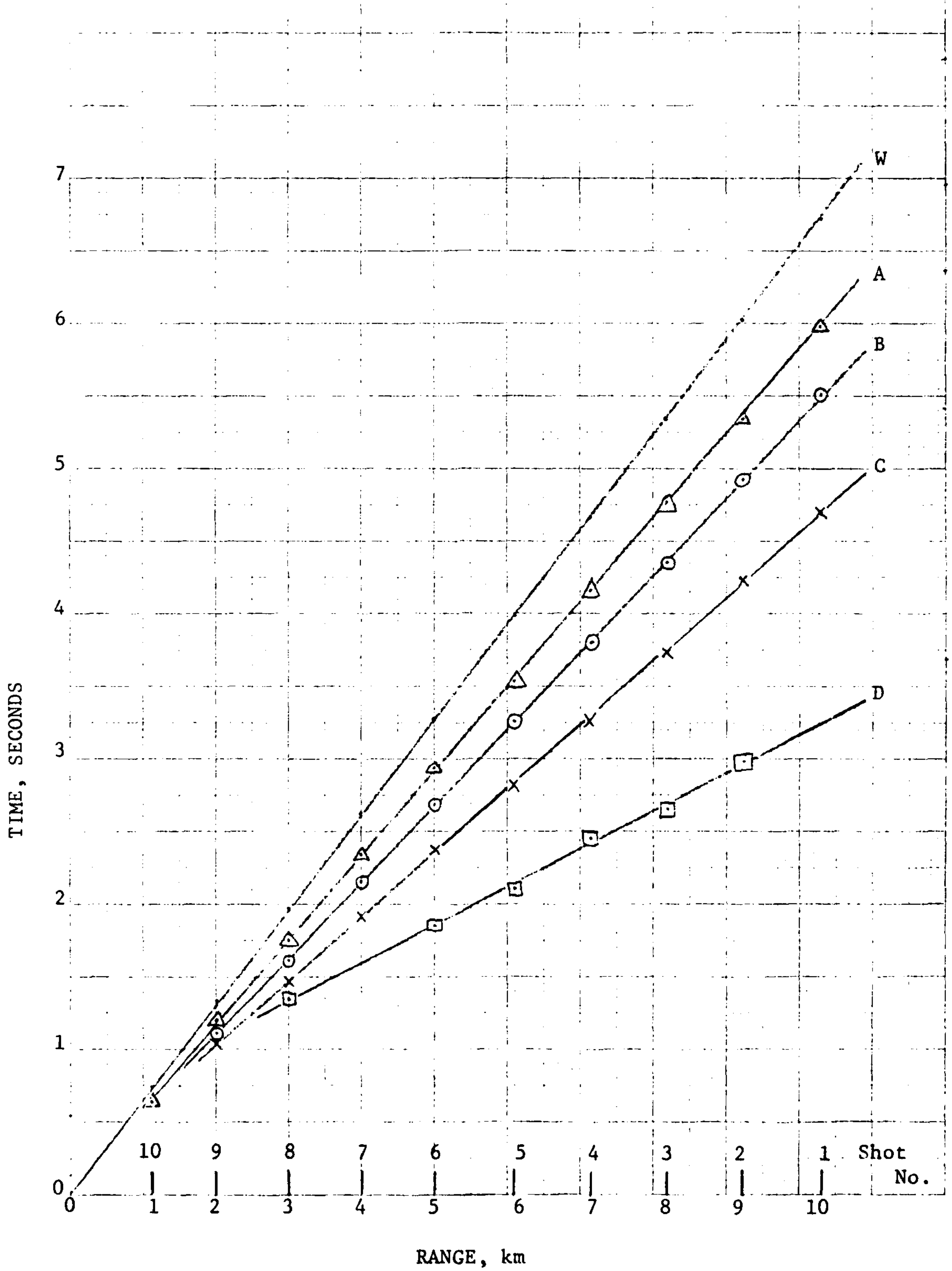


FIGURE 11

January 13, 1975
HSP:dcj
Serial No. R-1213

FIGURE 12

TRAVEL TIME VS. RANGE



DEPTH BENEATH
SURFACE, METERS

0

c_1 = 1533 m/sec. 42m

c_2 = 1723 m/sec. 38m

100

c_3 = 1884 m/sec. 177m

200

300

400

500

c_4 = 2271 m/sec. 478m

600

700

800

c_5 = 3820 m/sec.

PROPOSED SEDIMENTARY STRUCTURE

FIGURE 17

DISTRIBUTION LIST FOR TECHNICAL MEMORANDUM FILE NO. TM 75-12

Commander
Naval Sea Systems Command
Code 09G32 [Library]
Department of the Navy
Washington, D. C. 20362
Copy Nos. 1 and 2

Code SEA-03
Copy No. 3

Code SEA-0342
Copy No. 4

Code SEA-03E
Copy No. 5

Code PMS-407
Copy No. 6

Code SEA-663C
Copy No. 7

Chief of Naval Operations
Department of the Navy
Washington, D. C. 20350
Attention: Code NOP-325
Copy No. 8

Commanding Officer
Naval Surface Weapons Center
White Oak
Silver Spring, Maryland 20910
Attention: Code 054
Copy No. 9

Commanding Officer
Naval Coastal Systems Laboratory
Panama City, Florida 32401
Attention: Mr. R. J. Fyfe
Copy No. 10

Office of Naval Research
4555 Overlook Avenue, S.W.
Building 58, Room 227
Washington, D. C. 20375
Attention: CDR P. Tatro
Copy No. 11